Georgia Tech Ivan Allen College
School of Public Policy

Working Paper Series

Working Paper # 62

Health impacts from electromagnetic field exposure

Dr. Ronald N. Kostoff

May 2011

School of Public Policy

Georgia Institute of Technology
D. M. Smith Building
Room 107
685 Cherry Street
Atlanta, GA 30332 - 0345

Health impacts from electromagnetic field exposure

by

Dr. Ronald N. Kostoff

Research Affiliate, Georgia Institute of Technology, School of Public Policy

Home: 307 Yoakum Parkway, Unit 1821, Alexandria, VA 22304

Internet: ronald.kostoff@pubpolicy.gatech.edu; Phone: 571-527-0693

(DISCLAIMER: The views in this paper are solely those of the author, and do not necessarily represent the views of Georgia Institute of Technology or any of its components)

KEYWORDS: EMF; Electromagnetic Fields; Magnetic Fields; Radio Frequency Radiation; Microwave Radiation; Adverse Effects; Health Impacts; Text Mining; Citation Analysis

Unrestricted Public Access

ABSTRACT

This study overviews electromagnetic field (EMF) health impacts based on highly cited biomedical articles. It identifies health impacts resulting from exposure to EMF. A comprehensive query retrieved much of the relevant literature describing EMF health impacts, with strong emphasis on the mid and lower frequency non-ionizing (radio/microwave and power frequencies) portion of the electromagnetic spectrum. This retrieved literature was clustered algorithmically into sixteen biomedical sub-themes (assigned by the author). The highly cited papers and references in the thirteen most relevant of these sub-themes were analyzed, allowing the literature to be viewed through the filter of the most credible science.

Two of the thirteen relevant clusters addressed the use of EMF for therapeutic purposes: alleviating joint pain and accelerating healing of bone fractures, with some applications to treating carcinomas (e.g., hyperthermia). All the highly cited papers in these two clusters showed positive results, with varying degrees of the level of impact. The treatments tended to be relatively short exposures of EMF over relatively short periods of time.

The remaining eleven relevant clusters were divided into two main groups: (1) basic science research on the interaction of biological systems and organisms with EMF radiation; (2) epidemiological studies, focused mainly on population effects of occupational, residential, and mobile communications exposures to EMF. In group (1), broad agreement among the highly cited papers occurred in the following clusters: EMF interference with medical devices; cell phone neurological impacts; EMF-induced fields/currents in organisms; EMF impacts on calcium dynamics; gene expression/(heat shock protein) HSP induction of cells exposed to EMF; exposure of EMF on rat melatonin/oxidation/brain function; microwave radiation effects on proteins/cells/tissues, and sharp disagreements among the highly cited papers occurred in the following clusters: DNA/immune damage from cell exposure to EMF; cancer/embryo developmental effects on mice exposed to EMF.

Group (2) included: cancer risks from EMF exposure; health risks from magnetic field exposure. For 'cancer risks from EMF exposure', the results are mixed. However, there appears to be more agreement that a) occupational exposures to

EMF are associated with increased cancer risk than b) mobile phones are associated with increased cancer risk. Within the mobile phone literature, a statement from Kundi et al (2004) appears to reflect many (not all) from the broad range of results: there is evidence for enhanced cancer risk with increasing latency and duration of mobile phone use.

For 'health risks from magnetic field exposure', the focus of the highly cited papers tended to be on associations of childhood cancers (mainly leukemia) with magnetic field exposures. The results are mixed, ranging from no statistically significant associations to significant associations with relatively high magnetic field exposures.

INTRODUCTION

The electromagnetic radiation spectrum ranges from gamma rays (short wavelengths ~10^-13 meters and high frequencies ~10^21 Hz) to radio waves (long wavelengths ~10^2 meters and mid frequencies ~10^6 Hz) to the frequencies associated with commercial and residential power (very long wavelengths ~10^6 meters and very low frequencies~60Hz). Cell phone and wireless internet transmissions are in the RF (radio-frequency) range on the order of 10^6 Hz, while power frequencies in the 60 Hz range are typically referred to as Extremely Low Frequency (ELF).

Modern technology has introduced electromagnetic fields (EMF) with frequency signatures unfamiliar to the planet's organisms. Where once sunlight and its lunar reflections provided the bulk of the visible spectrum (with fire and lightening a distant second), now, many varieties of artificial light have complemented or replaced the sun as the main supplier. Additionally, EMF from other parts of the spectrum have become ubiquitous in daily life. In the last two or three decades, health concerns have been raised about EMF exposure from 1) mobile communication devices, 2) occupations, 3) residences, and 4) all other transmission sources.

The effects of electromagnetic fields on health range from therapeutic (e.g., "ELF-EMF modulates chemokine production and keratinocyte growth through inhibition of the NF-kappa B signalling pathway and thus may inhibit inflammatory processes. ELF-EMF could represent an additional therapeutic approach in the treatment of skin injury." (Vianale et al, 2008) or "ELF-EMF could augment the cell apoptosis effects of low doses of [radiotherapeutic] X-ray irradiation on [liver cancer cell line] BEL-7402 cells in a synergistic and cumulative way" (Wen et al, 2009)) to potentially harmful (e.g., "Extremely Low Frequency-Magnetic Fields (ELF-MF) are possible carcinogens to humans and some data suggest that they can act as promoters or progressors." (Gobba et al, 2009) or "Our study provides some evidence for the first time that MF exposure may have an adverse effect on sperm quality." (Li et al, 2010)).

Compounding the complexity of the problem further are the intrinsic limitations in the fundamental data. There are two main sources of data supporting the above arguments, and a number of additional sources.

a. Lab Experiments

One major source of data is isolated lab experiments on seemingly uniform biological systems, where only one or a very few parameters are varied. Even under these controlled conditions, output variation can have much wider spreads than in physical systems: (1) Individuals or groups in a population, which would usually be regarded as uniform, may react to EMF exposure in rather different or even opposite ways; (2) There seem to exist unknown and uncontrolled factors that determine the EMF sensitivity of a specimen or a population; e.g., irradiation could increase antibiotic resistivity in one experiment and decrease it in the other; (3) Even robust EMF effects may be well reproducible for a limited time and then disappear; (4) EMF effects could often be revealed only in subjects that are experiencing some deviation from the 'normal' state; (5) Increased sensitivity and even hypersensitivity of individual specimens to EMF exposure may be real (Pakhomov et al, 1998).

Even where laboratory uncertainties are relatively low, the question arises whether these lab results can be extrapolated to real world conditions in human beings, who are exposed to multiple forms of radiation with potential combined effects (e.g., "adverse effects of gamma-rays on cellular functions are strengthened by EMF" (Cao et al, 2009)), multiple drugs and pollutants, and other potentially damaging influences whose cumulative effects could be synergistic. As Verschaeve and Maes (1998) state in their review article on genetic, carcinogenic and teratogenic effects of radiofrequency fields: "we believe that synergistic investigations deserve special attention. Indeed, people are exposed to many different influences, and theoretically it may well be that a RF-exposure alone is ineffective whereas this exposure might enhance the mutagenicity, carcinogenicity or teratogenicity of chemical or physical factors". They provide the example of a synergistic effect from RF exposure preceding the mutagen mitomycin C in an investigation of 954-MHz waves emitted by the antenna of a GSM base station.

These EMF combined effects may go in multiple directions. As Whissel and Persinger (2007) state, in addressing the possibility of weak EMF as an enhancer of drug therapy: "Very weak (microT range) physiologically-patterned magnetic fields synergistically interact with drugs to strongly potentiate effects that have classically involved opiate, cholinergic, dopaminergic, serotonergic, and nitric oxide pathways. The combinations of the appropriately patterned magnetic fields and specific drugs can evoke changes that are several times larger than those evoked by the drugs alone." Additionally, as reflected in the provocative article titled "Do electromagnetic fields enhance the effects of environmental carcinogens?" (Juutilainen, 2008) and in a preceding article (Juutilainen et al, 2006), the EMF synergy could go in the opposite direction: "ELF MFs have been reported to enhance the effects of known carcinogenic or mutagenic agents in a few animal studies and in several in vitro studies.....The majority of in vitro studies have reported positive findings.....Animal studies designed according to the classical initiation-promotion concept may not be sufficient for studying the co-carcinogenic effects of MFs, and further studies using novel study designs would be useful".

There may even be a further complicating factor relative to synergistic effects. Most of these papers address combinations, but not their sequencing. For example, a paper published in Radiobiologia (Tikhonchuk, 1987) shows the critical importance of sequencing on the synergistic effect of microwave and gamma-ray radiation: "Structural and functional changes in the central nervous system were shown to be the same with both microwave and ionizing radiation having different mechanism of action. When the two types of radiation were delivered in a combination the sequence of delivery was of a significant importance. Antagonism of the effects was noted when microwave radiation was delivered prior to gamma-radiation. The effect was synergistic when the exposure to microwaves followed gamma-irradiation."

b. Epidemiological Studies

The other major type is epidemiological studies, which approach the problem from the other end of the parameter spectrum. Here, highly integrated data are taken. They contain the influence of many different types of parameters, genetic make-ups, and sequencing, only a very few of which may be taken into account. Thus,

what appears as a subtle effect over a large number of heterogeneous people may be a significant identifiable effect on a much smaller more homogeneous group if the effects of all the operational parameters and their sequencing were taken into account.

Given the importance of EMF in global daily life, one would think its potential health consequences would have received substantial scrutiny. That is not the case. There are many gaps in the published literature, and there are many studies that arrive at completely divergent conclusions. I have performed many text mining studies of different research disciplines and technologies over the past two decades. The literature on EMF health impacts is not that large relative to some of these previous studies, and the modest number of citations of its most highly cited articles (compared to some of the previous studies) reflects the modest number of people involved in researching EMF's health effects. There is a major disconnect between the importance of the EMF health impacts problem and the magnitude of the EMF health impacts research effort and its associated published literature!

The purpose of the present study is to gain/provide more insight on the broader health impacts of EMF. Text mining will be used to retrieve the relevant published literature, and then extract important information from this literature by a) filtering out the most credible data in this literature and b) identifying critical patterns in the filtered data. The next section provides some background material on text mining and EMF reviews, and is then followed by the approach, results, and conclusions. Additional background material on EMF is an intrinsic part of the study.

BACKGROUND

a. Text Mining

Text mining is the extraction of useful information from large volumes of text. Its central capability of computational linguistics was the main analytical technique used in the present study. Computational linguistics (Hearst, 1999; Losiewicz et al, 2000) identifies the main technical/medical themes of the database(s) being examined as well as the relationships among these themes. It has been used for a number of purposes including: enhancing information retrieval and increasing awareness of the global technical literature (Kostoff et al, 1997, 2000; Greengrass, 1997); discovery and innovation based on merging common linkages among very disparate literatures (Swanson, 1986; Kostoff, 2008); and uncovering unexpected asymmetries in the technical literature (Goldman et al, 1999; Kostoff, 2003).

A typical text mining study of the published literature involves the development of a query for comprehensive information retrieval, an analysis of the database using computational linguistics, and an integration of the processed information.

b. EMF Impacts

A more integrated picture of EMF health impacts has been drawn in the last decade, so this short section will summarize some recent EMF health impact reviews. The core of the present study presents a more detailed exposition of the EMF background.

While EMF health impact studies have covered the full EMF spectrum, most efforts have concentrated on the radiofrequency, power frequency, and pulsed segments, especially cell phones (and to a lesser degree WiFi) for the former. Recent RF reviews include: effects on the human nervous system (van Rongen et al, 2009), (Westerman and Hocking, 2004), (Hossmann and Hermann, 2003); neurological, behavioral, and carcinogenic effects (Habash et al, 2009), (Krewski et al, 2007), (Kaprana et al, 2008); brain activity (Valentini et al, 2007); mobile phone relationships to cancer (Kundi et al, 2004), (Toyran, 2008), (Moulder et al, 2005) (Khurana et al, 2009), (Colonna, 2005); blood-brain barrier effects (Stam, 2010); reproductive system effects (Desai et al, 2009); and genetic damage (Verschaeve, 2009), (Vijayalaxmi and Prihoda, 2008). Power frequency reviews

include: effects on avian reproduction (Fernie and Reynolds, 2005); relation to cancer (Kheifets et al, 2010); cellular effects (Santini et al, 2009); DNA effects (Blank, 2008); and blood-brain barrier effects (Nittby et al, 2008). Broad spectrum reviews include: brain activity effects (Carrubba and Marino, 2008); cellular effects (Funk and Monsees, 2006), (Kovacic and Somanathan, 2010); and embryonic morphogenesis (Levin, 2003). Overall, there tends to be general agreement that biological effects occur from EMFs, but there is a major split on whether that translates to health effects.

Pulsed EMF reviews include: arthritis therapy (Ganesan et al, 2009), (Fini et al, 2005); fracture healing (Einhorn, 1995), (Goldstein et al, 2010); wound healing (Cho, 2002); and drug delivery (Kaneda, 2010). Most reviews see a positive role for EMF-stimulated fracture and wound healing, joint pain alleviation, and drug delivery.

METHODS AND MATERIALS

The goal of this study is to identify the global literature relevant to assessing EMF impacts on health, and then to highlight and integrate the most credible elements of this literature. The approach used is to select the most credible global databases of research articles, develop a query that will retrieve the relevant global literature comprehensively, identify the key biomedical thrusts in the global literature, and then identify objectively the most credible studies within each thrust as judged by the broader biomedical community. These four approach components are now described in more detail.

Select Global Databases

The two premier biomedical research article databases are the Web of Science (WOS-Science Citation Index/Social Science Citation Index/Arts and Humanities Citation Index-SCI/SSCI/A&HCI) and Medline. Each has its unique strengths. WOS has the capability for citation linkages, while Medline has the unique MeSH taxonomy/keyword structure. Both were used in this study. The strengths of MeSH were used in query development, and the citation capability of WOS was used to identify highly cited records.

Develop Retrieval Query

The first step in query development is to define the scope of the study topic. The scope selected was health impacts of EMF directly interacting with organisms, with emphasis on assessing positive and negative effects from cell phones, overhead power lines, home wiring, transmission stations, occupational exposures, etc. An iterative relevance feedback technique (Kostoff et al, 1997) was used to develop the query. An initial test query, "EMF or electromagnetic field*", was inserted into Medline; records were retrieved and text patterns extracted; the query was then modified with some of these relevant text patterns, and the process was repeated until convergence (relatively few new relevant articles retrieved). Articles retrieved during the query development process were continually sampled for relevance. The final Abstract phrase patterns from Medline were inserted into the WOS, and are shown as the query in Appendix 1. The retrieval was further filtered by WOS Subject Area to biomedical topics, and filtered even further by journal theme.

Identify Key Biomedical Thrusts

The retrieved records were inserted into the text mining software package Vantage Point (VP) (Search, 2010) and into the CLUTO document clustering software package (Karypis, 2009). The packages were coupled to provide citations as a function of cluster (group). Text mining was performed on each group, to identify the key biomedical phrases representative of the group and the titles of papers in the group. Based on reading the titles and phrases, and reading of many paper Abstracts in the group as well, the theme of each group was identified.

Identifying the Most Credible Biomedical Thrust Elements

This is the key analytic step. It is based on the assumption that the most scientifically credible papers in the group are those that receive the most positive citations. Exceptions are always possible. An outstanding paper may have received little recognition from the larger community, or may have been sufficiently controversial that it never passed the peer-review process for publication. Or, a poor paper received substantial references, but they tended to focus on its inadequacies.

The most highly cited documents were identified two ways. First, the citations (references) in the retrieved papers in each cluster were examined, and the most highly cited that were relevant to the health effects theme of the cluster were extracted and analyzed. Their conclusions were summarized. Highly cited methodology papers and other general topical subjects were, for the most part, not included. Second, the retrieved papers in each cluster were examined themselves for times cited, and the most highly cited that were relevant to the health effects theme of the cluster were also extracted and analyzed. Any duplications between the two groups of highly cited documents from the same cluster were eliminated.

ANALYSIS AND RESULTS

There were 6614 records imported into VP, and 6053 records imported into CLUTO (only those with Abstracts). A hierarchical taxonomy (of biomedical themes) was generated with sixteen leaf (lowest level) clusters. This translates to an average of about 380 records per cluster, and represents a balance between output volume and resolution.

FIGURE 1 - TAXONOMY OF BIOMEDICAL THRUSTS IN EMF HEALTH EFFECTS LITERATURE

LEVEL 1	LEVEL 2	LEVEL 3
CL28: EMF impacts at patient/clinical level (2284)	CL26: EMF treatments; cell phone device interference, driving distractions (1375)	CL9: EMF treatment of medical conditions (495)
		CL1: EMF interference with medical devices (137)
		CL15: Cell phone neurological impacts (630)
		CL0: Cell phone driving distractions (113)
	CL22: EMF exposures; cancer risks, other health risks (909)	CL3: Cancer risks from EMF exposure (446)
		CL8: Health risks from magnetic field exposure (463)
CL29: EMF impacts at laboratory research/cellular level (3769)	CL27: Laboratory research on impacts of magnetic field exposures, especially at cellular levels (2838)	CL13: EMF-induced fields/currents in organisms (402)
		CL14: EMF impacts on calcium dynamics (571)
		CL2: Pulsed EMF for bone/fracture healing (324)
		CL4: Gene expression/hsp induction of cells exposed to EMF (263)
		CL10: DNA/immune damage from cell exposure to EMF (511)
		CL7: Cancer/embryo development effects on mice exposed to EMF (315)
		CL12: EMF exposure of animals melatonin/oxidation/brain function (452)

	CL20: Microwave irradiation for heating, staining, and reactions (931)	CL11: Microwave radiation effects on proteins/cells/tissues (399)
		CL6: Microwave-enhanced compounds and reactions (254)
		CL5: Microwave radiation for fixation to assist immunostaining (278)

The highest and lowest levels in the taxonomy (Figure 1) will now be described. The cluster numbers and order displayed in Figure 1 are those taken from the CLUTO output. The two categories in the highest level will be summarized in narrative form. Then, the categories (clusters) in the lowest level will be presented and discussed under the appropriate highest level category.

At the highest taxonomy level (Level 1 on Figure 1), the retrieved records were divided into two categories, labeled by the computer as Cluster 28 and Cluster 29. Cluster 28 contained 2284 records, was focused on various types of risks and diseases (and benefits) potentially resulting from EMF exposure, and, relatively speaking, could be viewed as impact at the macro level. Cluster 29 contained 3769 records, was focused on EMF interactions with organisms at the laboratory level, and could be viewed as impact at the micro level.

The lowest taxonomy level (Level 3 on Figure 1) contained, broadly speaking, three types of thrust areas. One type was use of EMF to treat medical conditions, concentrated in Clusters 2 and 9. The second type, the main focus of the present study, was potentially adverse (and positive) effects from EMF exposure, and the records were concentrated in eleven of the clusters.

The third type contained articles where EMF was mentioned in conjunction with diseases or injuries, but in a different sense from the main topic of this study. The three clusters in this class are highlighted in grey. Cluster 1 dealt with the use of cell phones while driving, and the damage that could result. Cluster 6 dealt with the use of microwaves to enhance reactions and biological synthesis, and Cluster 5 dealt with the use of microwave fixation to enhance immuno-staining. These three clusters will not be addressed further.

In addition, there were sub-sets of some clusters that were not relevant to the topic. For example, Cluster 9 contained a component that addressed use of mobile

communications for telemedicine and patient monitoring; this was deemed not relevant to the study, although it certainly is an important application. These non-relevant categories or sub-categories will be identified in the analysis section.

The output format for each of the lowest level clusters is as follows.

The first line is the cluster number (assigned by the computer clustering algorithm), followed by the number of records (within the cluster) in parenthesis. Thus, in the first of the lowest level clusters presented, the cluster number is 9, and the number of records in the cluster is 495. The next line is a short summary statement of the cluster theme.

These are followed by key excerpts from highly cited references (the most highly cited references in the papers that were imported into Vantage Point) and highly cited papers (the most highly cited of the papers that were imported into CLUTO), and an overall summary of their message.

I. CL28: EMF impacts at patient/clinical level (2284)

Ia. CL26: EMF treatments; cell phone device interference, driving distractions (1375)

Cluster 9 (495)

Theme: 1) Use of electromagnetic fields for treatment of medical conditions, including pain, neurological disorders, and carcinomas. 2) Also, use of mobile communication devices in telemedicine and patient monitoring (not relevant to main topic of study).

Highly Cited Documents

The papers with the most citations in this cluster focused on the value of mobile communications for telemedicine and patient monitoring, were deemed outside the main scope of this study, and were not included in the analysis. The most highly cited relevant papers showed the value of EMF technology for guiding invasive instruments and eliminating small carcinomas. The most cited references were

relevant to the topic, and showed the value of pulsed EMF for alleviating joint pain.

These highly cited documents emphasize the positive benefits possible from using EMF-based techniques. It should be noted that the EMF applications reflect short-term and/or short-pulsed applications. The highly-cited references emphasize pain reduction: pulsed electromagnetic fields [PEMF] for therapeutic benefit in painful osteoarthritis of the knee or cervical spine (Trock et al, 1993, 1994); the highly cited papers reflect imaging and coagulation: Real-time electromagnetic positioning technology coupled with previously acquired CT images augments standard bronchoscopy in reaching peripheral lung lesions and performing biopsies (Schwarz et al, 2003); percutaneous microwave coagulation therapy (PMCT) for complete remission of small hepatocellular carcinoma (Ohmoto et al, 1999).

Cluster 1 (137)

Theme: Electromagnetic interference of medical devices (especially implantable pacemakers and cardiac defibrillators) by electronic devices (especially cell phones)

Highly Cited Documents

The highly cited references cover cell phones, examining many different varieties. They indicate that if the cell phones are kept at a reasonable distance from the implant, they will not cause interference. The highly cited papers cover other devices as well. For the other devices, such as acousto-magnetic systems, there could be interference problems, depending on frequency and intensity of signal. It should be cautioned that the technologies reflect those of a decade ago, and some of the numbers may have changed due to improved shielding.

Highly-cited references provide guidelines for eliminating interference problems with implants, as do the highly cited papers, based on now decade-old technology: guidelines for distance between hand held phones/ portables from pacemakers (Irnich et al, 1996); guidelines for electromagnetic interference detection from remote distances and direct contact of phone antenna to skin (Barbaro et al, 1995); guidelines for cellular telephone placement for non-interference with pacemakers

(Hayes et al, 1997); guidelines for safe proximity between pacemakers and loudspeakers, acoustomagnetic systems, MRI, and cellular phones (Glikson and Friedman, 2001); warning patients with pacemakers about being in close proximity to acoustomagnetic systems (McIvor et al, 1998).

Cluster 15 (630)

Theme: Mobile phone impacts on health, especially neurological effects.

Highly Cited Documents

While most documents concluded that EMF decreased reaction times and promoted sleep, one highly cited reference noted an increase in suicides with exposure (Perry et al, 1981). Other highly cited references showed: REM suppressive effect with reduction of duration and percentage of REM sleep (Mann and Roschke, 1996); "pulsed high-frequency EMF in the range of radiotelephones may promote sleep and modify the sleep EEG." (Borberly et al, 1999); at 915 MHz, choice reaction time decreased (increase in speed) (Preece et al. 1999); "exposure to the electromagnetic field emitted by cellular telephones may have a facilitatory effect on brain functioning, especially in tasks requiring attention and manipulation of information in working memory" (Koivisto et al, 2000).

Ib. CL22: EMF exposures; cancer risks, other health risks (909)

Cluster 3 (446)

Theme: Cancer risks, emphasizing occupational and environmental electromagnetic field exposures

Highly Cited Documents

This is an important cluster relative to the theme of this study, and a larger number of highly cited documents have been included. While the results are mixed, there appears to be more agreement that 1) occupational exposures to EMF are associated with increased cancer risk than 2) mobile phones are associated with increased cancer risk. Within the mobile phone literature, a quote from Kundi et al

(2004) appears to reflect many (not all) from the broad range of results: there is evidence for enhanced cancer risk with increasing latency and duration of mobile phone use.

The highly cited epidemiology studies that reached the conclusion of higher risk for occupational exposure included: higher leukemia risk for workers who had more than the median cumulative exposure to magnetic fields (Theriault et al, 1994); higher brain tumor incidence for men employed in electricity-related occupations (Lin et al, 1985); modest elevation of brain cancer mortality in relation to duration of work in exposed jobs and much more strongly associated with magnetic field exposure indices (Savitz and Loomis, 1995); leukemia and the non-Hodgkin's lymphomas show increased proportionate mortality ratios (PMRs) in workers employed in occupations with intuitive exposures to electromagnetic fields (Milham, 1985); finally, it was proposed that increasing use of electricity for night lighting contributes to the rising risk of breast cancer globally (Stevens, 1987).

The highly cited epidemiology studies that reached the conclusion of higher risk for mobile phone exposure included: increased risk of acoustic neuroma associated with mobile phone use of at least 10 years' duration (Lonn et al, 2004); increased risk for brain tumour in the anatomical area close to the use of a cellular telephone (Hardell et al, 1999); evidence for enhanced cancer risk with increasing latency and duration of mobile phone use (Kundi et al, 2004).

Studies that find no association for mobile phones include: data do not support the hypothesis that the recent use of hand-held cellular telephones causes brain tumors (Inskip et al, 2001); data do not support the hypothesis of an association between use of mobile telephones and tumors of the brain or salivary gland, leukemia, or other cancers (Johansen et al, 2001); studies of cell phone use and power frequency electromagnetic fields have found little to support a causal connection with brain tumors (Wrensch et al, 2002).

Since latencies may be important (especially for cancer causation), but are unknown in the absence of long-term laboratory results or epidemiology results, long-term surveys may be required. Many studies did not have a sufficient long-term cohort to identify the emergence of long-term problems. Cell phone use has

been around for decades, but major expansion has taken place in the last decade. One problem with the use of highly cited references or highly cited papers is that there may be a substantial lag period, and in the case of cell phones would not have occurred at a time when large cohorts of long-term cell phone users were available for survey purposes.

A few papers on cell phone epidemiology studies published in 2008-2009 and cited highly relative to their contemporaries were examined to gather more long-term cohort user data. As shown below, there was almost general agreement that either risk was increased for brain tumors after ~ten year exposure from continual use (for those who had taken such long-term data) or there could be such increased risk for long-term exposure (for those who were aware of such data). However, one five-country study focused on meningioma only, and did not see an association with long term cell phone use. This latter study does not conflict with other recent results on brain tumors; the largest long-term effects tend to be related to gliomas and acoustic neuromas, rather than meningiomas. Finally, one study examined parotid gland tumors, and saw increased association with ipsilateral (same side) heavy cell phone use.

An evaluation of long-term use of mobile phones and the risk for brain tumors in case-control studies published so far showed a consistent pattern of an association between mobile phone use and ipsilateral glioma and acoustic neuroma using greater than ten year latency period (Hardell et al, 2008). A recommendation for more stringent EMF exposure guidelines concluded that new guidelines were warranted, since use of mobile phones is associated with an increased risk for brain tumor after 10 years (Hardell and Sage, 2008); a meta-analysis of 33 epidemiologic studies in the peer-reviewed literature concluded that there may be an increased risk of brain tumors, but its magnitude cannot be assessed at present because of insufficient information on long-term use (Kundi, 2009); a review of RF exposure from mobile phone use and tumor risk concluded that the studies published to date do not demonstrate an increased risk within approximately 10 years of use for brain or head tumor, but for slow-growing tumors, the absence of association is less conclusive because the observation period has been too short (Ahlbom et al, 2009); an international study concluded that the results do not provide support for an association between mobile phone use and risk of meningioma (Lahkola et al, 2008); a nationwide study of the association between cellular phone use and

development of parotid gland tumors (PGTs) suggested an association between cellular phone use and PGTs. (Sadetzki et al, 2008).

Cluster 8 (463)

Theme: Magnetic field exposures; potential health risks.

Highly Cited Documents

This is another important cluster, and more highly cited documents have been included The focus of the highly cited papers tended to be on associations of childhood cancers (mainly leukemia) with magnetic field exposures. The results are mixed, ranging from no statistically significant associations to significant associations with relatively high magnetic field exposures. All the papers deal with power frequency magnetic fields.

The initial cancer-power frequency EMF association study concluded that an excess of electrical wiring configurations suggestive of high current-flow was noted near the homes of children who developed cancer (Wertheimer and Leeper, 1979). Another case-control study for childhood cancers concluded that magnetic fields under low power use conditions had a modest association with cancer incidence; a cutoff score of 2.0 milligauss resulted in an odds ratio of 1.4 for total cancers and somewhat larger odds ratios (ORs) for leukemias (OR = 1.9), lymphomas (OR = 2.2), and soft tissue sarcomas (OR = 3.3) (Savitz et al, 1988); A study of tumor cases reported in the county of Stockholm for individuals 0-18 years of age concluded that magnetic fields of 0.3 microT or more were found twice as frequently among cases as among controls (Tomenius, 1986); The relation between exposure to electric and magnetic fields in the home and risk of leukemia showed an association between childhood leukemia risk and wiring configuration (London et al, 1993); A case-control study of high voltage power lines concluded the estimated relative risk for childhood leukemia was 2.7 for 0.2 microT and over, and 3.8 for 0.3 microT (Feychting and Ahlbom, 1993); Another study estimated the U.S. population attributable fraction of childhood leukemia associated with residential exposure is 3%, and suggested that appreciable magnetic field effects may be concentrated among relatively high and uncommon exposures (Greenland

et al, 2000); A study using instrumented pregnant women showed that daily prenatal short-time peak magnetic field exposures above a 16mg threshold resulted in significantly increased risk of miscarriage (Li et al, 2002).

Highly cited documents showing no associations include: "little evidence that living in homes characterized by high measured time-weighted average magnetic-field levels or by the highest wire-code category increases the risk of ALL [acute lymphoblastic leukemia] in children." (Linet et al, 1997); "no evidence that exposure to magnetic fields associated with the electricity supply in the UK increases risks for childhood leukaemia, cancers of the central nervous system, or any other childhood cancer." (Skinner et al, 2002); "results provide little support for a relation between power-frequency EMF exposure and risk of childhood leukemia." (McBride et al. 1999).

II. CL29: EMF impacts at laboratory research/cellular level (3769)

IIa. CL27: Laboratory research on impacts of magnetic field exposures, especially at cellular levels (2838)

Cluster 13 (402)

Theme: EMF-induced fields and currents in humans

Highly Cited Documents

The most cited references in this cluster are more along the lines of handbooks and methodology articles. The first is a series of guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields, and includes modeling issues (Ahlbom et al/ICNIRP, 1998). The next three articles were published in the same journal issue, and contain survey and original material on dielectric properties of biological tissues (Gabriel et al, 1996a; 1996b, 1996c). The next highly cited reference (Yee, 1966) presents a numerical technique for solving Maxwell's equations (which relate the E-field time derivative to the H-field space derivative), and these equations are necessary to model EMF propagation and interactions. The final highly cited reference describes a method to calculate

power deposition in biological bodies subjected to time varying magnetic fields (Orcutt and Gandhi, 1988).

The most highly cited papers in this cluster relate scalp potentials (using whole-head magnetoencephalography) to semantic context of sentences (Halgren et al, 2002), model how fish use self-generated electric fields to probe their environment and increase their ability to detect sensory stimuli (Chacron et al, 2001), and describe a method to calculate the ultimate intrinsic signal-to-noise ratio (SNR) in a magnetic resonance experiment for a point inside an arbitrarily shaped object (Ocali and Atalar, 1998).

Cluster 14 (571)

Theme: Magnetic field impacts on calcium dynamics

Highly Cited Documents

Many of the articles in this cluster examined the dynamics of calcium ions in magnetic fields. From a broader perspective, when one considers the different biological ions available (with their different masses and different charge-to-mass ratios), the different types of external electromagnetic fields that may be super-positioned (with their different frequencies, intensities, orientations, and pulse shapes), and the different constraints imposed on the motion of these ions by the properties of the surrounding biological materials, many types of synergies or antagonisms could be operable. These field-ion combinations could result in multiple types of resonances appearing simultaneously.

Liboff described ion-cyclotron resonance (Liboff, 1985), where magnetic fields alter the mobility of specific ions near the receptor sites. Following along those lines, Lednev offered the ion parametric resonance (IPR) theory (Lednev, 1991), in which the ion in the binding site is a charged harmonic oscillator. When the frequency of the alternating field is equal to the cyclotron frequency of this ion or to some of its harmonics or sub-harmonics, a resonant response of the biosystem to the magnetic field results. During this period, Blackman and collaborators showed that calcium ion effluxes from brain tissue could vary depending on the frequency and intensity of alternating electromagnetic field relative to other environmental

magnetic fields, in particular local geomagnetic fields (Blackman et al, 1985a, 1985b; Blanchard and Blackman, 1994). They believed that ambient magnetic field differences could explain discrepancies (among different groups) of effects of electromagnetic fields on biological systems.

One highly cited paper examined a broad swath of biological effects (mainly from Former Soviet Union research) from MMW radiation, and concluded that many reported MMW effects could not be readily explained by temperature changes during irradiation. Their conclusions stress the wide range of responses possible from seemingly uniform biological systems, and the implications from their findings are that many factors may be operable in determining the biological effects of MMW radiation on a specific organism or system, and synergies could magnify (or shield) the effects of the EMF (Pakhomov et al, 1998).

Another highly cited paper concerned absorption spectra for RF radiation, concluding that "the fundamental physical nature of the observed resonance structure is caused by the internal vibration modes in the macromolecules". (Globus et al, 2003)

Cluster 2 (324)

Theme: Pulsed EMF for bone/fracture healing.

Highly Cited Documents

There appears to be general agreement (in the highly cited literature) that EMF leads to improved healing of fractures; these EMF applications are all of short duration. The highly cited vintage paper from the 1950s concluded that "The origin to piezoelectricity in bone may be ascribed to the piezoelectric effect of the crystalline micelle of collagen molecules." (Fukada and Yasuda, 1957)

Other successful highly-cited EMF-based treatments include: successful treatment of 127 ununited fractures of the tibial diaphysis exclusively with pulsing electromagnetic fields. (Bassett et al, 1981); demonstration that clinically applied PEMF have a reproducible osteogenic effect in vitro and simultaneously induce BMP-2 and -4 mRNA transcription, supporting the concept that the two effects are

related (Bodamyali et al, 1998); demonstration that pulsed electromagnetic fields significantly influence healing in 45 tibial shaft fractures with delayed union (Sharrard, 1990); demonstration that electrical stimulation promotes the onset of motor axon regeneration without increasing its speed (Brushart et al, 2002).

Cluster 4 (263)

Theme: Gene expression/gene transcription and heat shock protein induction of cells exposed to electromagnetic fields.

Highly Cited Documents

Induction of heat shock and other stress protein expression by low frequency magnetic fields with low energy densities appears to be reflected in all the highly cited papers in this cluster. The range of effects includes: changes in gene transcription, suggesting "an important role for magnetic field exposure in altering cellular processes." (Phillips et al, 1992); a hypothesis that mobile phone radiation-induced activation of hsp27 may (i) facilitate the development of brain cancer by inhibiting the cytochrome c/caspase-3 apoptotic pathway and (ii) cause an increase in blood-brain barrier permeability through stabilization of endothelial cell stress fibers (Leszczynski et al, 2002); A study of heat shock stress showed that an effective magnetic stimulus evokes responses at an energy density 14 orders of magnitude lower than heat shock (Goodman and Blank, 1998); A follow on study concluded that the induction of stress gene HSP70 expression by exposure to EM fields provides insight into how EM fields interact with cells and tissues (Goodman and Blank, 2002); Another HSP study concluded that repeated exposure to mobile phone radiation acts as a repetitive stress leading to continuous expression of HSPs in exposed cells and tissues, which in turn affects their normal regulation, and cancer results (French et al, 2001).

Cluster 10 (511)

Theme: DNA and immune system damage from cell exposure to EMF.

Highly Cited Documents

Results in this cluster were mixed. Some studies reported definite DNA damage, whereas others reported none, albeit with caveats and reservations. Reports of definite DNA damage include: An exposure of rats to a 60 Hz magnetic field caused a dose-dependent increase in DNA strand breaks in brain cells, leading to the conclusion of possible health effects of exposure to 60 Hz magnetic fields (Lai and Singh, 1997); An exposure of rats to pulsed and continuous-wave 2450-MHz radiofrequency electromagnetic radiation resulted in DNA strand breaks in brain cells, leading to speculation that these effects could result from a direct effect of radiofrequency electromagnetic energy on DNA molecules and/or impairment of DNA-damage repair mechanisms in brain cells (Lai and Singh, 1996); Extended exposure to RF signals at an average SAR of at least 5.0 W/kg was capable of inducing chromosomal damage in human lymphocytes. (Tice et al, 2002); Intermittent exposure of human diploid fibroblasts to intermittent ELF-EMF resulted in a significant increase of DNA strand break levels, mainly DSBs, as compared to non-exposed controls, strongly indicating a genotoxic potential of intermittent EMF (Ivancsits et al, 2002).

The following first two documents were placed in Cluster 11 by the algorithm, but are more appropriate for the present cluster: For rats acutely exposed to low-intensity 2450 MHz microwaves, a dose rate-dependent increase in DNA single-strand breaks was found in brain cells. (Lai and Singh, 1995); a higher frequency of specific chromosome lesions in hamster cells irradiated at 7.7 GHZ suggested that microwave radiation causes changes in the synthesis as well as in the structure of DNA molecules. (Garaj-Vrhovac et al, 1990); Exposure of human peripheral blood lymphocytes to microwaves showed that microwaves are able to cause cytogenetic damage in human lymphocytes mainly for both high power density and long exposure time (Zotti-Martelli et al, 2000). Later experiments showed "that microwaves are able to induce MN in short-time exposures to medium power density fields " (Zotti-Martelli et al, 2005).

Reports that do not indicate DNA damage, but express caveats, include: A meta-analysis of studies for EMF genotoxic effects concluded that the preponderance of evidence suggests that ELF electric or magnetic fields do not have genotoxic potential (McCann et al, 1998); A meta-analysis of power frequency EMF exposure studies concluded that most of the available evidence does not suggest that electric and/or magnetic fields cause DNA damage (Murphy et al, 1993); A

meta-analysis of ELF-EMF exposure studies concluded that no convincing evidence currently exists that ELF-EMFs damage DNA either by point mutations, gross chromosomal alterations, or micronuclei formation (Lacy-Hulbert et al, 1998); A meta-analysis of data from over 100 studies concluded that RFR is not directly mutagenic and that adverse effects from exposure of organisms to high frequencies and high power intensities of RFR are predominantly the result of hyperthermia (Brusick et al, 1998).

Cluster 7 (315)

Theme: Cancer and embryo development effects on mice exposed to EMF

Highly Cited Documents

As in the DNA damage cluster, results in this embryo development cluster are mixed. Some studies report embryo development damage, while others report no damage. While one can understand the possibility of radically different conclusions from the (relatively uncontrolled) epidemiology studies, seeing these types of divergent conclusions from experiments under relatively controlled conditions is more disconcerting.

Studies reporting damage to embryo development include: Exposure of fertilized chicken eggs (10-1000 Hz) revealed the following effects: "Development of embryos was reduced to the formation of the three primitive layers. Brain vesicles, auditory pit, neural tube, foregut, heart, vessels, and somites were not developed. Glycosaminoglycans were almost absent." (Delgado et al, 1982); in chick embryos exposed to pulsed magnetic fields, more exposed embryos exhibited structural anomalies than did controls (Berman et al, 1990); chick embryos exposed to pulsed electromagnetic fields of 100 Hz led to observed malformations, possibly due to induced alterations in extracellular glycosaminoglycans (Ubeda et al, 1983); mice exposed long-term to pulse-modulated RF fields similar to those used in digital mobile telecommunications showed lymphoma risk to be significantly higher in the exposed mice than in the controls, with follicular lymphomas being the major contributor to the increased tumor incidence (Repacholi et al, 1997).

Studies that reported no embryo development damage include: Exposure of fertilized chicken eggs to pulsed trains of square wave magnetic fields with pulse repetition rates of 100 or 1000 showed no differences between exposed, sham-exposed and control eggs. (Maffeo et al, 1984); Long-term exposure of mice to GSM-modulated 898.4 MHz radiation showed "no significant effects when compared to sham-irradiated animals." (Utteridge et al, 2002); chronic, low-level exposure of mammary-tumor-prone mice to 2450 MHz radiofrequency radiation (RFR) "did not affect mammary tumor incidence, latency to tumor onset, tumor growth rate, or animal longevity when compared with sham-irradiated controls." (Frei et al, 1998).

Cluster 12 (452)

Theme: Impacts of rat exposures to magnetic fields on melatonin, oxidation, and brain function

Highly Cited Documents

The highly cited documents in this cluster show an increase in oxidative stress from EMF and decrease in melatonin production. Documents showing an oxidative stress increase include: Exposure of rabbits to 900 MHz digital GSM mobile telephone radiation showed that serum super-oxide dismutase activity increased, and serum nitric oxide levels decreased, indicating "the possible role of increased oxidative stress in the pathophysiology of adverse effect of EMR." (Irmak et al, 2002); acute exposure of healthy male volunteers to radiofrequency fields of commercially available cellular phones led researchers to conclude that such exposure "may modulate the oxidative stress of free radicals by enhancing lipid peroxidation and reducing the activation of SOD and GSH-Px, which are free radical scavengers." (Moustafa et al, 2001); Exposure of rats to 900MHz mobile phone radiation showed "Reactive oxygen species may play a role in the mechanism that has been proposed to explain the biological side effects of MP [mobile phones], and Gb [Ginko Biloba] prevents the MP-induced oxidative stress to preserve antioxidant enzymes activity in brain tissue." (Ilhan et al, 2004).

Highly cited documents showing a melatonin decrease include: Exposure of rats to a 50-Hz rotating magnetic field showed a significant decrease of melatonin (Kato et al, 1993); exposure of twelve men to a 40Hz magnetic field showed significant depression in nocturnal melatonin rise (Karasek et al, 1998); evaluation of cellular phone use in two populations of male utility workers showed that "Prolonged use of cellular telephones may lead to reduced melatonin production, and elevated 60-Hz MF exposures may potentiate the effect." (Burch et al, 2002).

Documents relating to brain damage include: exposure of rats to GSM mobile phone electromagnetic fields showed "highly significant ($p < 0.002$) evidence for neuronal damage in the cortex, hippocampus, and basal ganglia in the brains of exposed rats." (Salford et al, 2003); exposure of twelve men to RF EMF similar to mobile phones showed "pulse modulation of RF EMF is necessary to induce changes in the waking and sleep EEG, and substantiates the notion that pulse modulation is crucial for RF EMF-induced alterations in brain physiology." (Huber et al, 2005).

Cluster 11 (399)

Theme: Microwave radiation and heating effects on proteins, cells, and tissues.

Highly Cited Documents

The highly cited references in this cluster all showed non-thermal effects of EMF on proteins, cells, and tissues. Most of the highly cited papers in this cluster dealt with (relatively small) thermal effects from (mainly) microwave imaging devices. A few dealt with non-thermal effects, and the latter are included here.

Documents describing changes in bacteria/cells include: "Microwave radiation in Escherichia coli and Bacillus subtilis cell suspensions resulted in a dramatic reduction of the viable counts as well as increases in the amounts of DNA and protein released from the cells" (Woo et al, 2000); sublethal microwave radiation exposure of Staphylococcus aureus cells led to increased activities of malate and alpha-ketoglutarate dehydrogenases, cytochrome oxidase, and cytoplasmic adenosine triphosphatase, decreased activity of glucose-6-phosphate dehydrogenase, and increased levels of thermonuclease activity (Dreyfuss and

Chipley, 1980); glucan was shown to be a potent protector against microwave radiation-induced lipid peroxidation cell damage in phosphatidylcholine liposomes (Babincova et al, 1999).

The three final documents in this cluster address impacts on protein and human blood lymphocytes: exposure to microwave radiation enhanced the aggregation of bovine serum albumin and promoted amyloid fibril formation by bovine insulin, and was not accompanied by measurable temperature changes (De Pomerai et al, 2003); microwave radiation caused measurable stress to transgenic nematodes, demonstrating clear biological effects of microwave radiation in terms of the activation of cellular stress responses (HSP gene induction). (Daniells et al, 1998); exposure of enzymes to 10.4 GHz microwave radiation suggested that microwaves induce protein structural rearrangements not related to temperature. (Porcelli et al, 1997).

DISCUSSION AND CONCLUSIONS

A comprehensive query was developed to retrieve much of the relevant literature describing health impacts of EMF, with strong emphasis on the lower frequency non-ionizing (radio/microwave and power frequencies) portion of the spectrum. This retrieved literature was clustered algorithmically into sixteen biomedical sub-themes (assigned by the author), and the highly cited papers and references in the thirteen most relevant of these sub-themes were analyzed. Highly cited papers were viewed as a potential filter that would allow the literature to be viewed through the prism of the most credible science.

Two of the thirteen relevant clusters addressed the use of EMF for therapeutic purposes. In the EMF range covered by the query, the main focus was alleviating joint pain and accelerating healing of bone fractures, with some additional effort devoted to treating carcinomas (e.g., hyperthermia). All the highly cited papers in these two clusters showed positive results, with varying degrees of the level of impact. The treatments tended to be relatively short exposures of EMF over relatively short periods of time.

The remaining eleven relevant clusters are divided into two main groups for purposes of discussion. One group could be described as basic science research on the interaction of biological systems and organisms with EMF radiation. The second group could be described as epidemiological studies, focused mainly on population effects of occupational exposures to EMF, residential exposures to EMF, and exposures to EMF from mobile communications.

a. Basic Science Group

a1. General Agreement within Clusters

The first sub-group discussed contains clusters in which there was general agreement. For 'EMF interference with medical devices', the highly cited documents cover cell phones mainly, examining many different varieties. These documents indicate that if the cell phones are kept at a reasonable distance from the implanted medical device, they will not cause interference. The documents provide specific guidelines for safety. For other devices, such as acousto-magnetic

systems, there could be interference problems, depending on frequency and intensity of signal.

For 'cell phone neurological impacts', most documents concluded that EMF decreased reaction times and promoted sleep, but one reference noted an increase in suicides with EMF exposure. For 'EMF-induced fields/currents in organisms', the most cited references are more along the lines of handbooks and methodology articles, with much computer modeling involved. For 'EMF impacts on calcium dynamics', the highly cited articles attempted to explain differences among existing studies, rather than generate new experiments with further differences. Some of the articles involved modeling the plasma dynamics of charged particles in magnetic fields, where the fields could be superpositions of different external fields. Other articles addressed the allied problem of the wide range of biological system parameters that could influence the plasma dynamics. When one considers the different biological ions available (with their different masses and different charge-to-mass ratios), the different types of external electromagnetic fields that may be super-positioned (with their different frequencies, intensities, orientations, and pulse shapes), and the different constraints imposed on the motion of these ions by the properties of the surrounding biological materials, many types of synergies or antagonisms could be operable. These field-ion combinations could result in multiple types of resonances appearing simultaneously.

For 'gene expression/hsp induction of cells exposed to EMF', induction of heat shock and other stress protein expression by low frequency magnetic fields with low energy densities appears to be reflected in all the highly cited papers. These effects can be stimulated by magnetic fields with many orders of magnitude lower energy densities than thermal stimuli. For 'exposure of EMF on rat melatonin/oxidation/brain function', the highly cited documents show an increase in oxidative stress from EMF, a decrease in melatonin production, and an increase in some markers of brain damage. For 'microwave radiation effects on proteins/cells/tissues', the highly cited references all showed non-thermal effects of EMF on proteins, cells, and tissues. Most of the highly cited papers in this cluster dealt with (relatively small) thermal effects from (mainly) microwave imaging devices. A few dealt with non-thermal effects, and were included in the analysis.

a2. No General Agreement within Clusters

The second sub-group discussed contains clusters in which there was not general agreement. For 'DNA/immune damage from cell exposure to EMF', results were mixed. Some studies reported definite DNA damage, whereas others reported none, albeit with caveats and reservations. Most of the highly cited reports on DNA damage (3/5) were produced by Lai and Singh, and they were very specific. The five studies that did not report DNA damage tended to have caveats at the end, allowing for the possibility of such damage in the future. It is unclear to me why such glaring discrepancies exist, and this point will be discussed further at the end of this section.

For 'cancer/embryo developmental effects on mice exposed to EMF', as in the DNA damage cluster, results in this cluster are mixed. Some studies report embryo development damage, while others report no damage. While one can understand the possibility of radically different conclusions from the (relatively uncontrolled) epidemiology studies, seeing these types of divergent conclusions from experiments under relatively controlled conditions is more disconcerting.

b. Epidemiological Studies Group

The epidemiology studies group included 'cancer risks from EMF exposure' and 'health risks from magnetic field exposure'. For 'cancer risks from EMF exposure', a larger number of highly cited documents have been included because of its importance to the theme of the study. While the results are mixed, there appears to be more agreement that occupational exposures to EMF are associated with increased cancer risk than mobile phones are associated with increased cancer risk. Within the mobile phone literature, the last clause from the Kundi reference paragraph (Kundi et al, 2004) appears to reflect many (not all) from the broad range of results: there is evidence for enhanced cancer risk with increasing latency and duration of mobile phone use.

For 'health risks from magnetic field exposure', this is another important cluster relative to the study's theme, and a larger number of highly cited documents have been included The focus of the highly cited papers tended to be on associations of childhood cancers (mainly leukemia) with magnetic field exposures (power frequencies). The results are mixed, ranging from no statistically significant

associations to significant associations with relatively high magnetic field exposures.

It is difficult to draw conclusions from these diverse epidemiological studies. Each study tends to be performed by a specific group on a specific population, or sub-population, typically in the country where a majority of the researchers work. The funding sources for each study, the approaches, the environments, the cultural habits, and the objectives may all differ. Especially in the mobile phone studies, most, if not all, of the data are generated by personal recall. In addition, there are phone technologies and phone use habits, along with operational environments, that may have changed over time. Many variables, whose importance cannot be discounted without further study (such as sequencing-when was the phone used relative to other activities; synergy-what other activities/drugs/foods/toxins were being used, etc) were not taken into account.

Since latencies may be important (especially for cancer causation), but are unknown in the absence of long-term laboratory results or epidemiology results, long-term surveys may be required. Many studies did not have a sufficient long-term cohort to identify the emergence of long-term problems. Cell phone use has been around for decades, but major expansion has taken place in the last decade. One problem with the present study's use of highly cited references or highly cited papers is that there may be a substantial lag period between when a highly cited paper was published and the present. Especially in the case of cell phones, the studies referenced would not have included adequate data where large cohorts of long-term users were available for survey purposes.

To circumvent this lag problem somewhat, a few papers on cell phone epidemiology studies published in 2008-2009 and cited highly relative to their contemporaries were examined to gather more long-term cohort user data. There was almost general agreement from these more recent studies that either risk was increased for brain tumors after ~ten year exposure from continual use (for those who had taken such long-term data) or there could be such increased risk for long-term exposure (for those who were aware of such data). However, one five-country study focused on meningioma only, and did not identify an association with long term cell phone use. This latter study does not conflict with other recent results on brain tumors; the largest long-term effects from these other studies tend

to be related to gliomas and acoustic neuromas, rather than meningiomas. Finally, one recent study examined parotid gland tumors, and saw increased association with ipsilateral (same side) heavy cell phone use.

But even these recent surveys do not tell the full story. Given data gathering, analysis, and publishing lag times, the long-term data of interest in these recent surveys probably represent technologies and EMF usage patterns reflective of the early to mid-1990s. Since that time, new drugs and pollutants have been introduced, new electronic medical diagnostic devices are in operation, electric-powered cars and cars with more onboard electronics have expanded, offices with greater concentrations of electronic equipment operating at different frequencies are more prevalent, buildings/schools with internal wireless networks have expanded greatly, and mobile communications usage patterns have changed and increased substantially. Many more people have cell phones (requiring a higher density of cell phone towers/masts), and the phones have far more diverse capabilities, increasing the opportunity for substantially greater usage. Many more children, the most vulnerable age group, have phones, and there are more diverse uses for phones with larger attendant social networks. Since there is evidence, as shown in the Introduction, that EMF may be a promoter/sensitizer of adverse (and positive) effects as well as an initiator, the effects of these new technologies acting synergistically with expanded mobile communication use (and other occupational and residential EMF exposures) cannot be discounted. Thus, new synergies with potentially long impact latency periods may be possible, and will not be amenable through today's most recent epidemiological studies.

Two near/mid-term steps are recommended to address some of these short-comings, a retro-active and pro-active component. For the retro-active component, disagreements in the critical data identified above need to be resolved. Two approaches are recommended. A Science Court (Kantrowitz, 1967) should be convened for each major thrust area identified above in which major disagreements exist. This approach was modeled after legal procedures for dispute resolution, and was applied successfully by the present author to select among alternative magnetic fusion concepts in 1977 (DOE, 1978). It would be most appropriate for the present application. The second approach would select major areas of disagreement where strong adverse effects have been shown or predicted by the proponents. These studies, focused on the conditions that produced these adverse

effects, would be re-done with multiple performers representing diverse viewpoints participating. The study criteria would match objectives, methodology, and operational environment as closely as possible. Any differences in results could be examined on a uniform basis.

Second, for the pro-active component, lab studies emphasizing EMF sources operating in concert with new potential synergy technologies should be initiated. Given the history of this research, multiple groups with diverse histories should be funded to address a given problem uniformly, as above. There are obviously severe limitations with this second recommendation. The extrapolation from relatively pristine lab animal-based results (with only a few parameters varied even in synergistic studies) to human beings operating in a complex multi-parameter world is not necessarily clear. Even if adverse (or positive) effects are not shown in the lab, this does not mean they will not occur in the real world. Nonetheless, given that the EMF genie is out of the bottle, this band-aid catch-up approach is probably the best that can be accomplished.

REFERENCES

Ahlbom A, Bergqvist U, Bernhardt JH, Cesarini JP, Court LA, Grandolfo M, Hietanen M, McKinlay AF, Repacholi MH, Sliney DH, Stolwijk JAJ, Swicord ML, Szabo LD, Taki M, Tenforde TS, Jammet HP, Matthes R/ ICNIRP. Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz). International Commission on Non-Ionizing Radiation Protection. Health Phys. 74(4):494-522. 1998

Ahlbom A, Feychting M, Green A, Kheifets L, Savitz DA, Swerdlow AJ. ICNIRP Standing Comm Epidemiol. Epidemiologic evidence on mobile phones and tumor risk a review. Epidemiology. 20(5). 639-652. 2009.

Babincová M, Machová E, Kogan G. Carboxymethylated glucan inhibits lipid peroxidation in liposomes. Z Naturforsch C. 54(12). 1084-8. 1999.

Barbaro V, Bartolini P, Donato A, Militello C, Altamura G, Ammirati F, Santini M. Do European GSM mobile cellular phones pose a potential risk to pacemaker patients? Pace-Pacing and Clinical Electrophysiology. 18(6). 1218-1224. 1995.

Bassett CA, Mitchell SN, Gaston SR. Treatment of ununited tibial diaphyseal fractures with pulsing electromagnetic fields. J Bone Joint Surg Am. 63(4). 511-23. 1981.

Bassett CA, Becker RO. Generation of electric potentials by bone in response to mechanical stress. Science. 137(3535). 1063-1064. 1962.

Berman E, Chacon L, House D, Koch BA, Koch WE, Leal J, Lovtrup S, Mantiply E, Martin AH, Martucci GI, Mild KH, Monahan JC, Sandstrom M, Shamsaifar K, Tell R, Trillo MA, Ubeda A, Wagner P. Development of chicken embryos in a pulsed magnetic field. Bioelectromagnetics. 11(2). 169-87. 1990.

Blackman CF, Benane SG, Rabinowitz JR, House DE, Joines WT. A role for the magnetic-field in the radiation-induced efflux of calcium-ions from brain-tissue invitro. Bioelectromagnetics. 6(4). 327-337. 1985a.

Blackman CF, Benane SG, House DE, Joines WT. Effects of ELF (1-120 hz) and modulated (50 hz) RF fields on the efflux of calcium-ions from brain-tissue invitro. Bioelectromagnetics. 6(1). 1-11. 1985b.

Blanchard JP, Blackman CF. Clarification and application of an ion parametric resonance model for magnetic-field interactions with biological-systems. Bioelectromagnetics. 15(3). 217-238. 1994.

Blank M . Protein and DNA reactions stimulated by electromagnetic fields. Electromagnetic Biology and Medicine. 27:1. 3-23. 2008.

Bodamyali T, Bhatt B, Hughes FJ, Winrow VR, Kanczler JM, Simon B, Abbott J, Blake DR, Stevens CR. Pulsed electromagnetic fields simultaneously induce osteogenesis and upregulate transcription of bone morphogenetic proteins 2 and 4 in rat osteoblasts in vitro. Biochem Biophys Res Commun. 250(2). 458-61. 1998.

Borbely AA, Huber R, Graf T, Fuchs B, Gallmann E, Achermann P. Pulsed high-frequency electromagnetic field affects human sleep and sleep electroencephalogram. Neuroscience Letters. 275(3). 207-210. 1999.

Brushart TM, Hoffman PN, Royall RM, Murinson BB, Witzel C, Gordon T. Electrical stimulation promotes motoneuron regeneration without increasing its speed or conditioning the neuron. Journal of Neuroscience. 22(15). 6631-6638. 2002.

Brusick D, Albertini R, McRee D, Peterson D, Williams G, Hanawalt P, Preston J. DNA Genetox Expert Panel. Genotoxicity of radiofrequency radiation. Environmental and Molecular Mutagenesis. 32(1). 1-16. 1998.

Burch JB, Reif JS, Noonan CW, Ichinose T, Bachand AM, Koleber TL, Yost MG. Melatonin metabolite excretion among cellular telephone users. International Journal of Radiation Biology. 78(11). 1029-1036. 2002.

Cao Y, Zhang W, Lu MX, Xu Q, Meng QQ, Nie JH, Tong J. 900-MHz Microwave radiation enhances -ray adverse effects on SHG44 cells. Journal of Toxicology and Environmental Health-Part A-Current Issues. 72(11-12). 727-732. 2009.

Carrubba S, Marino AA. The effects of low-frequency environmental-strength electromagnetic fields on brain electrical activity: A critical review of the literature. Electromagnetic Biology and Medicine. 27:2. 83-101. 2008.

Chacron MJ, Longtin A, Maler L. Negative interspike interval correlations increase the neuronal capacity for encoding time-dependent stimuli. J Neurosci. 21(14). 5328-43. 2001.

Cho MR. A review of electrocoupling mechanisms mediating facilitated wound healing. IEEE Transactions on Plasma Science. 30:4. 1504-1515. Part 1. 2002.

Colonna A. Cellular phones and cancer: current status. Bulletin du Cancer. 92:7-8. 637-643. 2005.

Daniells C, Duce I, Thomas D, Sewell P, Tattersall J, de Pomerai D. Transgenic nematodes as biomonitors of microwave-induced stress. Mutat Res. 399(1). 55-64. 1998.

de Pomerai DI, Smith B, Dawe A, North K, Smith T, Archer DB, Duce IR, Jones D, Candido EP. Microwave radiation can alter protein conformation without bulk heating. FEBS Lett. 543(1-3). 93-7. 2003.

Delgado JMR, Leal J, Monteagudo JL, Gracia MG. Embryological changes induced by weak, extremely low-frequency electromagnetic-fields. Journal of Anatomy. 134. 533-551. 1982.

Desai NR, Kesari KK, Agarwal A. Pathophysiology of cell phone radiation: oxidative stress and carcinogenesis with focus on male reproductive system. Reproductive Biology and Endocrinology. 7:114. 2009.

DOE. Evaluation of Alternate Magnetic Fusion Concepts 1977. DOE/ET 0047, U.S. Department of Energy, Assistant Secretary for Energy Technology, Office of Fusion Energy. May 1978.

Dreyfuss MS, Chipley JR. Comparison of effects of sublethal microwave radiation and conventional heating on the metabolic activity of Staphylococcus aureus. Appl Environ Microbiol. 39(1). 13-6. 1980.

Einhorn TA. Enhancement of fracture-healing. Journal of Bone and Joint Surgery-American Volume. 77A:6. 940-956. 1995.

Fernie KJ and Reynolds SJ. The effects of electromagnetic fields from power lines on avian reproductive biology and physiology: A review. Journal of Toxicology and Environmental Health-Part B-Critical Reviews, 8 (2): 127-140. 2005.

Feychting M, Ahlbom A. Magnetic fields and cancer in children residing near Swedish high-voltage power lines. Am J Epidemiol. 138(7). 467-81. 1993.

Fini M, Giavaresi G, Carpi A, Nicolini A, Setti S, Giardino R. Effects of pulsed electromagnetic fields on articular hyaline cartilage: review of experimental and clinical studies. Biomedicine & Pharmacotherapy. 59:7. 388-394. 2005.

Frei MR, Berger RE, Dusch SJ, Guel V, Jauchem JR, Merritt JH, Stedham MA. Chronic exposure of cancer-prone mice to low-level 2450 MHz radiofrequency radiation. Bioelectromagnetics. 19(1). 20-31. 1998.

French PW, Penny R, Laurence JA, McKenzie DR. Mobile phones, heat shock proteins and cancer. Differentiation. 67(4-5). 93-97. 2001.

Fukada E and Yasuda I. On the piezoelectric effect of bone. J. Phys. Soc. Jpn. 12. 1158-1162. 1957.

Funk RHW, Monsees TK. Effects of electromagnetic fields on cells: Physiological and therapeutical approaches and molecular mechanisms of interaction. Cells Tissues Organs. 182:2. 59-78. 2006.

Gabriel C, Gabriel S, and Corthout E. The dielectric properties of biological tissues: I. Literature survey. Phys. Med. Biol. 41. 2231-2249. 1996a.

Gabriel S, Lau RW and Gabriel C. The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz. Phys. Med. Biol. 41. 2251-2269. 1996b.

Gabriel S, Lau RW and Gabriel C. The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues. Phys. Med. Biol. 41. 2271-2293. 1996c.

Ganesan K, Gengadharan AC, Balachandran C, Manohar BM, Puvanakrishnan R. Low frequency pulsed electromagnetic field - A viable alternative therapy for arthritis. Indian Journal of Experimental Biology. 47:12. 939-948. 2009.

Garaj-Vrhovac V, Horvat D, Koren Z. The effect of microwave-radiation on the cell genome. Mutation Research. 243(2). 87-93. 1990.

Glikson M, Friedman PA. The implantable cardioverter defibrillator. Lancet. 357(9262). 1107-1117. 2001.

Globus TR, Woolard DL, Khromova T, Crowe TW, Bykhovskaia M, Gelmont BL, Hesler J, Samuels AC. THz-spectroscopy of biological molecules. Journal of Biological Physics. 29(2-3). 89-100. 2003.

Gobba F, Bargellini A, Scaringi M, Bravo G, Borella P. Extremely Low Frequency-Magnetic Fields (ELF-EMF) occupational exposure and natural killer activity in peripheral blood lymphocytes. Science of the Total Environment. 407 (3). 1218-1223. 2009.

Goldman JA, Chu, WW, Parker, DS, Goldman, RM. Term domain distribution analysis: a data mining tool for text databases. Methods of Information in Medicine. 38. 96-101. 1999.

Goldstein C, Sprague S, Petrisor BA. Electrical Stimulation for Fracture Healing: Current Evidence. Journal of Orthopaedic Trauma. 24. S62-S65. Suppl. 1. 2010.

Goodman R, Blank M. Insights into electromagnetic interaction mechanisms. Journal of Cellular Physiology. 192(1). 16-22. 2002.

Goodman R, Blank M. Magnetic field stress induces expression of hsp70. Cell Stress & Chaperones. 3(2). 79-88. 1998.

Greengrass E. Information retrieval: An overview. National Security Agency. TR-R52-02-96. 1997.

Greenland S, Sheppard AR, Kaune WT, Poole C, Kelsh MA. A pooled analysis of magnetic fields, wire codes, and childhood leukemia. Childhood Leukemia-EMF Study Group. Epidemiology. 11(6). 624-34. 2000.

Habash RWY, Elwood JM, Krewski D, Lotz WG, McNamee JP, Prato FS. Recent advances in research on radiofrequency fields and health: 2004-2007. Journal of Toxicology and Environmental Health-Part B-Critical Reviews. 12 (4): 250-288 2009.

Halgren E, Dhond RP, Christensen N, Van Petten C, Marinkovic K, Lewine JD, Dale AM. N400-like magnetoencephalography responses modulated by semantic context, word frequency, and lexical class in sentences. Neuroimage. 17(3). 1101-16. 2002.

Hardel, L, Sage C. Biological effects from electromagnetic field exposure and public exposure standards. Biomedicine & Pharmacotherapy. 62 (2). 104-109. 2008.

Hardell L, Näsman A, Påhlson A, Hallquist A, Hansson Mild K. Use of cellular telephones and the risk for brain tumours: A case-control study. International Journal of Oncology. (1). 113-6. 1999.

Hardell, L, Carlberg, M, Soderqvist, F, Mild, KH. Meta-analysis of long-term mobile phone use and the association with brain tumours. International Journal of Oncology. 32 (5). 1097-1103. 2008.

Hayes DL, Wang PJ, Reynolds DW, Estes NAM, Griffith JL, Steffens RA, Carlo GL, Findlay GK, Johnson CM. Interference with cardiac pacemakers by cellular telephones. New England Journal of Medicine. 336(21). 1473-1479. 1997.

Hearst MA. Untangling text data mining. Proceedings of ACL 99, the 37th Annual Meeting of the Association for Computational Linguistics. University of Maryland, June 20-26. 1999.

Hossmann KA, Hermann DM. Effects of electromagnetic radiation of mobile phones on the central nervous system. Bioelectromagnetics. 24:1. 49-62. 2003.

Huber R, Treyer V, Schuderer J, Berthold T, Buck A, Kuster N, Landolt HP, Achermann P. Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow. European Journal of Neuroscience. 21(4). 1000-1006. 2005.

Ilhan A, Gurel A, Armutcu F, Kamisli S, Iraz M, Akyol O, Ozen S. Ginkgo biloba prevents mobile phone-induced oxidative stress in rat brain. Clinica Chimica Acta. 340(1-2). 153-162. 2004.

Inskip PD, Tarone RE, Hatch EE, Wilcosky TC, Shapiro WR, Selker RG, Fine HA, Black PM, Loeffler JS, Linet MS. Cellular-telephone use and brain tumors. New England Journal of Medicine. 344(2). 79-86. 2001.

Irmak MK, Fadilloglu E, Gulec M, Erdogan H, Yagmurca M, Akyol O. Effects of electromagnetic radiation from a cellular telephone on the oxidant and antioxidant levels in rabbits. Cell Biochemistry and Function. 20(4). 279-283. 2002.

Irnich W, Batz L, Muller R, Tobisch R. Electromagnetic interference of pacemakers by mobile phones. Pace-Pacing and Clinical Electrophysiology. 19(10). 1431-1446. 1996.

Ivancsits S, Diem E, Pilger A, Rudiger HW, Jahn O. Induction of DNA strand breaks by intermittent exposure to extremely-low-frequency electromagnetic fields in human diploid fibroblasts. Mutation Research-Genetic Toxicology and Environmental Mutagenesis. 519(1-2). 1-13. 2002.

Johansen C, Boice J Jr, McLaughlin J, Olsen J. Cellular telephones and cancer - A nationwide cohort study in Denmark. J Natl Cancer Inst. 93(3). 203-7. 2001.

Juutilainen J, Kumlin T, Naarala J. Do extremely low frequency magnetic fields enhance the effects of environmental carcinogens? A meta-analysis of experimental studies. International Journal of Radiation Biology. 82(1). 1-12. 2006.

Juutilainen J. Do electromagnetic fields enhance the effects of environmental carcinogens? Radiation Protection Dosimetry. 132(2). 228-231. 2008.

Kaneda Y. Update on non-viral delivery methods for cancer therapy: possibilities of a drug delivery system with anticancer activities beyond delivery as a new therapeutic tool. Expert Opinion on Drug Delivery. 7:9. 1079-1093. 2010.

Kantrowitz A. Proposal for an institution for scientific judgment. Science. 153. 763. 1967.

Kaprana AE, Karatzanis AD, Prokopakis EP, Panagiotaki IE, Vardiambasis IO, Adamidis G, Christodoulou P, Velegrakis GA. Studying the effects of mobile phone use on the auditory system and the central nervous system: a review of the

literature and future directions. European Archives of Oto-Rhino-Laryngology. 265:9. 1011-1019. 2008.

Karasek M, Woldanska-Okonska M, Czernicki J, Zylinska K, Swietoslawski J. Chronic exposure to 2.9 mT, 40 Hz magnetic field reduces melatonin concentrations in humans. Journal of Pineal Research. 25(4). 240-244. 1998.

Karypis G. CLUTO—A clustering toolkit. http://www.cs.umn.edu/˜cluto. 2009.

Kato M, Honma K, Shigemitsu T, Shiga Y. Effects of exposure to a circularly polarized 50-hz magnetic-field on plasma and pineal melatonin levels in rats. Bioelectromagnetics. 14:2. 97-106. 1993.

Kheifets L, Renew D, Sias G, Swanson J. Extremely low frequency electric fields and cancer: assessing the evidence. Bioelectromagnetics. 31:2. 89-101. 2010.

Khurana VG, Teo C, Kundi M, Hardell L, Carlberg M. Cell phones and brain tumors: a review including the long-term epidemiologic data. Surgical Neurology. 72:3. 205-214. 2009.

Koivisto M, Revonsuo A, Krause C, Haarala C, Sillanmaki L, Laine M, Hamalainen H. Effects of 902 MHz electromagnetic field emitted by cellular telephones on response times in humans. Neuroreport. 11(2). 413-415. 2000.

Kostoff RN, Eberhart HJ, and Toothman DR, Database Tomography for information retrieval. Journal of Information Science. 23:4. 301-311. 1997.

Kostoff RN, Braun T., Schubert A, Toothman DR., and Humenik J. Fullerene roadmaps using bibliometrics and Database Tomography. Journal of Chemical Information and Computer Science. 40:1. 19-39. Jan-Feb 2000.

Kostoff RN. Bilateral asymmetry prediction. Medical Hypotheses. 61:2. 265-266. 2003.

Kostoff RN. Literature-Related Discovery: Introduction and background. Technological Forecasting and Social Change. 75:2. 165-185. 2008.

Kovacic P, Somanathan R. Electromagnetic fields: mechanism, cell signaling, other bioprocesses, toxicity, radicals, antioxidants and beneficial effects. Journal of Receptors and Signal Transduction. 30:4. 214-226. 2010.

Krewski D, Glickman BW, Habash RWY, Habbick B, Lotz WG, Mandeville R, Prato FS, Salem T, Weaver DF. Recent advances in research on radiofrequency fields and health: 2001-2003. Journal of Toxicology and Environmental Health-Part B-Critical Reviews. 10 (4): 287-318. 2007.

Kundi M, Mild KH, Hardell L, Mattsson MO. Mobile telephones and cancer - A review of epidemiological evidence. Journal of Toxicology and Environmental Health-Part B-Critical Reviews. 7:5. 351-384 2004.

Kundi M. The Controversy about a Possible Relationship between Mobile Phone Use and Cancer. Environmental Health Perspectives. 117(3). 316-324. 2009.

Lacy-Hulbert A, Metcalfe JC, Hesketh R. Biological responses to electromagnetic fields. FASEB Journal. 12(6). 395-420. 1998.

Lahkola, A, Salminen, T, Raitanen, J, Heinavaara, S, Schoemaker, MJ, Christensen, HC, Feychting, M, Johansen, C, Klaeboe, L, Lonn, S, Swerdlow, AJ, Tynes, T, Auvinen, A. Meningioma and mobile phone use - a collaborative case-control study in five North European countries. International Journal Of Epidemiology. 37 (6). 1304-1313. 2008.

Lai H, Singh NP. Acute exposure to a 60 Hz magnetic field increases DNA strand breaks in rat brain cells. Bioelectromagnetics. 18(2). 156-165. 1997.

Lai H, Singh NP. Acute low-intensity microwave exposure increases DNA single-strand breaks in rat-brain cells. Bioelectromagnetics. 16(3). 207-210. 1995.

Lai H, Singh NP. Single- and double-strand DNA breaks in rat brain cells after acute exposure to radiofrequency electromagnetic radiation. International Journal of Radiation Biology. 69(4). 513-521. 1996.

Lednev VV. Possible mechanism for the influence of weak magnetic-fields on biological-systems. Bioelectromagnetics. 12(2). 71-75. 1991.

Leszczynski D, Joenväärä S, Reivinen J, Kuokka R. Non-thermal activation of the hsp27/p38MAPK stress pathway by mobile phone radiation in human endothelial cells: molecular mechanism for cancer- and blood-brain barrier-related effects. Differentiation. 70(2-3). 120-9. 2002.

Levin M. Bioelectromagnetics in morphogenesis. Bioelectromagnetics. 24:5. 295-315. 2003.

Li DK, Odouli R, Wi S, Janevic T, Golditch I, Bracken TD, Senior R, Rankin R, Iriye R. A population-based prospective cohort study of personal exposure to magnetic fields during pregnancy and the risk of miscarriage. Epidemiology. 13:1. 9-20. 2002.

Li DK, Yan B, Li Z, Gao ES, Miao MH, Gong DM, Weng XP, Ferber JR, Yuan W. Exposure to magnetic fields and the risk of poor sperm quality. Reproductive Toxicology. 29(1). 86-92. 2010.

Liboff, AR. Cyclotron resonance in membrane transport. In A. Chiabrera, C. Nicolini, & H. P. Schwan (Eds.), Interactions between in interactions between electromagnetic fields and cells. 281–396. New York: Plenum Press. 1985.

Lin RS, Dischinger PC, Conde J, Farrell KP. Occupational exposure to electromagnetic-fields and the occurrence of brain-tumors - an analysis of possible associations. Journal of Occupational and Environmental Medicine. 27(6). 413-419. 1985.

Linet MS, Hatch EE, Kleinerman RA, Robison LL, Kaune WT, Friedman DR, Severson RK, Haines CM, Hartsock CT, Niwa S, Wacholder S, Tarone RE. Residential exposure to magnetic fields and acute lymphoblastic leukemia in children. N Engl J Med. 337(1). 1-7. 1997.

London SJ, Thomas DC, Bowman JD, Sobel E, Cheng TC, Peters JM. Exposure to residential electric and magnetic fields and risk of childhood leukemia. Am J Epidemiol. 134(9). 923-37. 1991.

Lönn S, Ahlbom A, Hall P, Feychting M. Mobile phone use and the risk of acoustic neuroma. Epidemiology. 15(6). 653-9. 2004.

Losiewicz P, Oard D, Kostoff RN. Textual data mining to support science and technology management. Journal of Intelligent Information Systems. 15. 99-119. 2000.

Maffeo S, Miller MW, Carstensen EL. Lack of effect of weak low frequency electromagnetic fields on chick embryogenesis. J Anat. 139 (Pt 4). 613-8. 1984.

Mann K, Roschke J. Effects of pulsed high-frequency electromagnetic fields on human sleep. Neuropsychobiology. 33(1). 41-47. 1996.

McBride ML, Gallagher RP, Thériault G, Armstrong BG, Tamaro S, Spinelli JJ, Deadman JE, Fincham S, Robson D, Choi W. Power-frequency electric and magnetic fields and risk of childhood leukemia in Canada. Am J Epidemiol. 149(9). 831-42. 1999.

McCann J, Dietrich F, Rafferty C. The genotoxic potential of electric and magnetic fields: an update. Mutat Res. 411(1). 45-86. 1998.

McIvor ME, Reddinger J, Floden E, Sheppard RC, Johnson D, Becker GI, Mayotte M. Study of pacemaker and implantable cardioverter defibrillator triggering by electronic article surveillance devices (SPICED). Pace-Pacing and Clinical Electrophysiology. 21(10). 1847-1861. 1998.

Milham S. Mortality in workers exposed to electromagnetic-fields. Environmental Health Perspectives. 62. 297-300. 1985.

Moulder JE, Foster KR, Erdreich LS, McNamee JP. Mobile phones, mobile phone base stations and cancer: a review. International Journal of Radiation Biology. 81:3. 189-203. 2005.

Moustafa YM, Moustafa RM, Belacy A, Abou-El-Ela SH, Ali FM. Effects of acute exposure to the radiofrequency fields of cellular phones on plasma lipid peroxide and antioxidase activities in human erythrocytes. Journal of Pharmaceutical and Biomedical Analysis. 26(4). 605-608. 2001.

Murphy JC, Kaden DA, Warren J, Sivak A. International Commission for Protection Against Environmental Mutagens and Carcinogens. Power frequency electric and magnetic fields: a review of genetic toxicology. Mutat Res. 296(3). 221-40. 1993.

Nittby H, Grafstrom G, Eberhardt JL, Malmgren L, Brun A, Persson BRR , Salford LG. Radiofrequency and extremely low-frequency electromagnetic field effects on the blood-brain barrier. Electromagnetic Biology and Medicine. 27:2. 103-126. 2008.

Ocali O, Atalar E. Ultimate intrinsic signal-to-noise ratio in MRI. Magn Reson Med. 39(3). 462-73. 1998.

Ohmoto K, Miyake I, Tsuduki M, Shibata N, Takesue M, Kunieda T, Ohno S, Kuboki M, Yamamoto S. Hepato-Gastroenterology. 46(29). 2894-2900. 1999.

Orcutt N, Gandhi OP. A 3-D impedance method to calculate power deposition in biological bodies subjected to time varying magnetic fields. IEEE Trans Biomed Eng. Aug. 35(8). 577-83. 1988.

Pakhomov AG, Akyel Y, Pakhomova ON, Stuck BE, Murphy MR. Current state and implications of research on biological effects of millimeter waves: A review of the literature. Bioelectromagnetics. 19(7). 393-413. 1998.

Perry FS, Reichmanis M, Marino AA, Becker RO. Environmental power-frequency magnetic-fields and suicide. Health Physics. 41(2). 267-277. 1981.

Phillips JL, Haggren W, Thomas WJ, Ishida-Jones T, Adey WR. Magnetic field-induced changes in specific gene transcription. Biochim Biophys Acta. 1132(2). 140-4. 1992.

Porcelli M, Cacciapuoti G, Fusco S, Massa R, dAmbrosio G, Bertoldo C, DeRosa M, Zappia V. Non-thermal effects of microwaves on proteins: Thermophilic enzymes as model system. FEBS Letters. 402(2-3). 102-106. 1997.

Preece AW, Iwi G, Davies-Smith A, Wesnes K, Butler S, Lim E, Varey A. Effect of a 915-MHz simulated mobile phone signal on cognitive function in man. International Journal of Radiation Biology. 75(4). 447-456. 1999.

Repacholi MH, Basten A, Gebski V, Noonan D, Finnie J, Harris AW. Lymphomas in E mu-Pim1 transgenic mice exposed to pulsed 900 MHZ electromagnetic fields. Radiat Res. 147(5). 631-40. 1997.

Sadetzki, S, Chetrit, A, Jarus-Hakak, A, Cardis, E, Deutch, Y, Duvdevani, S, Zultan, A, Novikov, I, Freedman, L, Wolf, M. Cellular phone use and risk of benign and malignant parotid gland tumors - A nationwide case-control study. American Journal of Epidemiology. 167 (4). 457-467. 2008.

Salford LG, Brun AE, Eberhardt JL, Malmgren L, Persson BRR. Nerve cell damage in mammalian brain after exposure to microwaves from GSM mobile phones. Environmental Health Perspectives. 111(7). 881-883. 2003.

Santini MT, Rainaldi G, Indovina PL. Cellular effects of extremely low frequency (ELF) electromagnetic fields. International Journal of Radiation Biology. 85:4. 294-313. 2009.

Savitz DA, Loomis DP. Magnetic field exposure in relation to leukemia and brain cancer mortality among electric utility workers. Am J Epidemiol. 15. 141(2). 123-34. 1995.

Savitz DA, Wachtel H, Barnes FA, John EM, Tvrdik JG. Case-control study of childhood cancer and exposure to 60-Hz magnetic fields. Am J Epidemiol. 128(1). 21-38. 1988.

Schwarz Y, Mehta AC, Ernst A, Herth F, Engel A, Besser D, Becker HD. Electromagnetic navigation during flexible bronchoscopy. Respiration. 70(5). 516-522. 2003.

Search Technology, Norcross, GA. 2010.

Sharrard WJ. A double-blind trial of pulsed electromagnetic fields for delayed union of tibial fractures. J Bone Joint Surg Br. 72(3):347-55. 1990.

Skinner J, Mee TJ, Blackwell RP, Maslanyj MP, Simpson J, Allen SG, Day NE, Cheng KK, Gilman E, Williams D, Cartwright R, Craft A, Birch JM, Eden OB, McKinney PA, Deacon J, Peto J, Beral V, Roman E, Elwood P, Alexander FE, Mott M, Chilvers CE, Muir K, Doll R, Taylor CM, Greaves M, Goodhead D, Fry FA, Adams G, Law G; United Kingdom Childhood Cancer Study Investigators. Exposure to power frequency electric fields and the risk of childhood cancer in the UK. Br J Cancer. 87(11). 1257-66. 2002.

Stam R. Electromagnetic fields and the blood-brain barrier. Brain Research Reviews. 65:1 80-97 2010.

Stevens RG. Electric-power use and breast-cancer - a hypothesis. American Journal of Epidemiology. 125(4). 556-561. 1987.

Swanson DR, Fish oil, Raynauds syndrome, and undiscovered public knowledge, Perspct. Biol. Med. 30 (1) (1986) 7–18.

Theriault G, Goldberg M, Miller Ab, Armstrong B, Guenel P, Deadman J, Imbernon E, To T, Chevalier A, Cyr D, Wall C. Cancer risks associated with occupational exposure to magnetic-fields among electric utility workers in Ontario and Quebec, Canada, and France - 1970-1989. American Journal of Epidemiology. 139(6). 550-572. 1994.

Tice RR, Hook GG, Donner M, McRee DI, Guy AW. Genotoxicity of radiofrequency signals. I. Investigation of DNA damage and micronuclei induction in cultured human blood cells. Bioelectromagnetics. 23(2). 113-126. 2002.

Tikhonchuk VS, Ushakov IB, Fedorov VP. Structural and metabolic analysis of the reaction of the central nervous system to the combined action of microwave and ionizing radiations. Radiobiologiia. 27(3). 361-5. 1987.

Tomenius L. 50-Hz electromagnetic environment and the incidence of childhood tumors in Stockholm County. Bioelectromagnetics. 7(2). 191-207. 1986.

Toyran N. The effect of cellular phone on cancer: review. Turkiye Klinikleri Tip Bilimleri Dergisi. 28:6. 933-941. 2008.

Trock DH, Bollet AJ, Dyer RH, Fielding LP, Miner WK, Markoll R. A double-blind trial of the clinical effects of pulsed electromagnetic-fields in osteoarthritis. Journal of Rheumatology. 20(3). 456-460. 1993.

Trock DH, Bollet AJ, Markoll R. The effect of pulsed electromagnetic-fields in the treatment of osteoarthritis of the knee and cervical-spine - report of randomized, double-blind, placebo-controlled trials. Journal of Rheumatology. 21(10). 1903-1911. 1994.

Ubeda A, Leal J, Trillo MA, Jimenez MA, Delgado JM. Pulse shape of magnetic fields influences chick embryogenesis. J Anat. 137 (Pt 3). 513-36. 1983.

Utteridge TD, Gebski V, Finnie JW, Vernon-Roberts B, Kuchel TR. Long-term exposure of E-mu-Pim1 transgenic mice to 898.4 MHz microwaves does not increase lymphoma incidence. Radiat Res. 158(3). 357-64. 2002.

Valentini E, Curcio G, Moroni F, Ferrara M, De Gennaro L, Bertini M. Neurophysiological effects of mobile phone electromagnetic fields on humans: A comprehensive review. Bioelectromagnetics. 28:6. 415-432. 2007.

van Rongen E, Croft R, Juutilainen J, Lagroye, I, Miyakoshi J, Saunders R, de Seze R, Tenforde T, Verschaeve L, Veyret B, Xu ZP. Rffects of radiofrequency electromagnetic fields on the human nervous system. Journal of Toxicology and Environmental Health-Part B-Critical Reviews, 12 (8): 572-597. 2009.

Verschaeve L, Maes A. Genetic, carcinogenic and teratogenic effects of radiofrequency fields. Mutat Res. 410(2). 141-65. 1998.

Verschaeve L. Genetic damage in subjects exposed to radiofrequency radiation. Mutation Research-Reviews in Mutation Research. 681:2-3. 259-270. 2009.

Vianale G, Reale M, Amerio P, Stefanachi M, Di Luzio S, Muraro R. Extremely low frequency electromagnetic field enhances human keratinocyte cell growth and decreases proinflammatory chemokine production. British Journal Of DermatologY. 158 (6). 1189-1196. 2008.

Vijayalaxmi, Prihoda TJ. Genetic damage in mammalian somatic cells exposed to radiofrequency radiation: A meta-analysis of data from 63 publications (1990-2005). Radiation Research. 169:5. 561-574. 2008.

Wen J, Zhao W, Cheng ZQ, Fang Z. X-Ray-Induced apoptosis of BEL-7402 cell line enhanced by extremely low frequency electromagnetic field in vitro. Bioelectromagnetics. 30(2) 163-165. 2009.

Wertheimer N, Leeper E. Electrical wiring configurations and childhood cancer. Am J Epidemiol. 109(3). 273-84. 1979.

Westerman R, Hocking B. Diseases of modern living: neurological changes associated with mobile phones and radiofrequency radiation in humans. Neuroscience Letters. 361:1-3. 13-16. 2004.

Whissell PD, Persinger MA. Emerging synergisms between drugs and physiologically-patterned weak magnetic fields: Implications for neuropharmacology and the human population in the twenty-first century. Current Neuropharmacology. 5(4). 278-288. 2007.

Woo IS, Rhee IK, Park HD. Differential damage in bacterial cells by microwave radiation on the basis of cell wall structure. Applied and Environmental Microbiology. 66(5). 2243-2247. 2000.

Wrensch M, Minn Y, Chew T, Bondy M, Berger MS. Epidemiology of primary brain tumors: current concepts and review of the literature. Neuro Oncol. 4(4). 278-99. 2002.

Yee KS. Numerical solution of initial boundary value problems involving maxwells equations in isotropic media. IEEE Transactions on Antennas and Propagation. AP14:3. 302-307. 1966.

Zotti-Martelli L, Peccatori M, Maggini V, Ballardin M, Barale R. Individual responsiveness to induction of micronuclei in human lymphocytes after exposure in vitro to 1800-MHz microwave radiation. Mutat Res. 582(1-2). 42-52. 2005.

Zotti-Martelli L, Peccatori M, Scarpato R, Migliore L. Induction of micronuclei in human lymphocytes exposed in vitro to microwave radiation. Mutat Res. 472(1-2). 51-8. 2000.

APPENDIX 1 - QUERY USED FOR INFORMATION RETRIEVAL

The query is the intersection of the EMF terms below and hundreds of specific and general biomedical terms (e.g., DNA, wound healing, behavioral effects, thyroid, cancer, etc), restricted to biomedical SCI Subject Areas.

(EMF OR "ELECTROMAGNETIC FIELD*" OR "RADIO-FREQUENCY RADIATION" OR "RADIO-FREQUENCY IRRADIATION" OR "RF-RADIATION" OR "RF-IRRADIATION" OR "MICROWAVE RADIATION" OR "MICROWAVE IRRADIATION" OR "MOBILE PHONE*" OR "CELL* PHONE*" OR "WIRELESS PHONE*" OR "CORDLESS PHONE*" OR "MOBILE TELEPHONE*" OR "CELLULAR TELEPHONE*" OR "WIRELESS TELEPHONE*" OR "CORDLESS TELEPHONE*" OR "BASE STATION*" OR "RF-TRANSMISSION TOWER*" OR (("MAGNETIC FIELD*" OR "ELECTRIC FIELD*") AND ("POWER LINE*" OR "LOW FREQUENCY" OR "POWER FREQUENCY" OR "INTERMEDIATE FREQUENCY" OR "TRANSMISSION LINE*" OR "ELECTRIC POWER TRANSMISSION")))